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Instituting a filtration/pressurization system to reduce dust concentrations in a control room at a mineral processing plant

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Abstract

The National Institute for Occupational Safety and Health has observed that many control rooms and operator compartments in the U.S. mining industry do not have filtration systems capable of maintaining low dust concentrations in these areas. In this study at a mineral processing plant, to reduce respirable dust concentrations in a control room that had no cleaning system for intake air, a filtration and pressurization system originally designed for enclosed cabs was modified and installed. This system was composed of two filtering units: one to filter outside air and one to filter and recirculate the air inside the control room. Eighty-seven percent of submicrometer particles were reduced by the system under static conditions. This means that greater than 87 percent of respirable dust particles should be reduced as the particle-size distribution of respirable dust particles is greater than that of submicrometer particles, and filtration systems usually are more efficient in capturing the larger particles. A positive pressure near 0.02 inches of water gauge was produced, which is an important component of an effective system and minimizes the entry of particles, such as dust, into the room. The intake airflow was around 118 cfm, greater than the airflow suggested by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) for acceptable indoor air quality. After one year, the loading of the filter caused the airflow to decrease to 80 cfm, which still produces acceptable indoor air quality. Due to the loading of the filters, the reduction efficiency for submicrometer particles under static conditions increased to 94 percent from 87 percent.

Introduction

Chronic overexposure to respirable silica dust (particle diameter < 10 micrometers) leads to a progressive lung disease known as silicosis. Workers who develop silicosis have increased incidence of lung cancer and pulmonary disorders. In June 1997, the International Agency for Research on Cancer (1997) found sufficient evidence to declare that inhaled crystalline silica in the form of quartz and cristobalite is carcinogenic. Mining is one of the leading

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industries for occupational exposure to silica dust (Scarselli et al., 2011; Vacek et al., 2011; Kreiss and Zhen, 1996; Healy et al., 2014; Merget et al., 2001; Hewett et al., 2012). Control rooms located in dusty areas in some mines are of particular concern (Colinet et al., 2010).

Many mineral processing operations house workers who are performing particular job functions in operator compartments and/or control rooms. Many industrial processing mills have rooms where a worker looks out over the facility and has direct control over the product flow throughout the entire building. In addition, primary crusher operators are often located in a compartment from which they are able to view the primary crushing function. Their job is to control when trucks dump into the primary jaw crusher and the rate of feed of the ore from the hopper into the crusher. Many of these control rooms and operator booths do not have filtration systems capable of cleaning air entering the room or booth, which can result in elevated concentrations of dust in them. To reduce the dust concentrations, it would make sense to clean the entering air with filtration and pressurization units similar to those proven to provide clean environments in enclosed cabs.

A filtration and pressurization unit designed for enclosed cabs was modified to operate in a control room at a milling plant. This paper describes the system's performance and the air quality resulting from its implementation.

Background on filtration and pressurization systems

The National Institute for Occupational Safety and Health's (NIOSH) Office of Mine Safety and Health Research (OMSHR) has performed extensive research on filtration and pressurization systems for the enclosed cabs of mobile equipment for many years (Cecala et al., 2014). Early on in this research effort, numerous in-cab dust sources were identified that increased the equipment operator's respirable exposure, including dust-laden work clothing, work boots, control panels, and dust on the cab's inside walls (Cecala et al., 2001, 2004, 2005 and 2007). A comprehensive laboratory study was performed to evaluate the various factors and parameters that are critical for an effective filtration and pressurization system in an enclosed cab (Organiscak and Cecala, 2009a, 2009b; Organiscak et al., 2008).

The field and laboratory studies determined that the two most significant components of an effective system are: (1) a competent filtration system comprised of a pressurized intake and a recirculation component and (2) an enclosure with sufficient structural integrity to achieve positive pressurization. An effective pressurized intake air component provides numerous important functions in an optimized system. First, it provides the required amount of outside air to ensure the equipment operator has acceptable indoor air quality as specified by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE, 2010). Secondly, it creates enough positive pressurization to stop contaminants from being drawn into an enclosure. High-efficiency intake filters are necessary for an effective design. For enclosures for mining applications, a minimum efficiency reporting value-16 (MERV-16) intake mechanical filter has worked extremely well for reducing dust and diesel particulate matter while providing the necessary airflow, pressure and filter life (Noll et al., 2012, 2014).

A recirculation system is a vital component of any filtration and pressurization system design, and the range of operating parameters that can be used in an effective system is wide. First, the filtration efficiency of the recirculation filter should be between MERV-14 and MERV-16. The mining conditions should dictate the actual filter efficiency rating chosen, based on parameters such as dust type, silica content, dust sources and levels in the enclosure, and how often miners enter or exit the area. Finally, it must be remembered that the system's ultimate effectiveness is based on the reductions achieved through multiple cycles of filtering the interior cab air (Organiscak and Cecala, 2009a, 2009b).

To ensure enclosure integrity, testing has shown that installing new door gaskets and seals and plugging and sealing cracks and holes in the enclosure's shell have a major impact on increasing enclosure pressurization. Further, to prevent the infiltration of dust-laden air, the enclosure's static pressure must be higher than the wind's velocity pressure (Heitbrink et al., 2000).

The use of a unidirectional airflow pattern should also be considered whenever possible to maximize the air quality in the operator's breathing zone inside the enclosure. In systems without a unidirectional design, both the intake and discharge for the recirculation air are normally located in the roof, which causes the dust-laden air in the enclosure to be pulled directly over the worker as it is drawn into the ventilation system. Further, in many designs, the contaminated return air and the clean filtered air are ducted within inches of each other in the ceiling. This poor design allows for recirculated air to be short-circuited and allows dustladen return air to be pulled directly back into the ventilation system and over the operator's breathing zone. A more effective design is to draw the recirculated air from the bottom of the enclosure, away from the breathing zone (Cecala et al., 2010).

The previously gathered information and knowledge can be adapted for control rooms, but although operator booths and control rooms are somewhat similar to enclosed cabs on mobile mining equipment, there are key differences:

- Enclosed vehicle cabs are constantly being stressed and subjected to leakage issues by the equipment movement. Operator compartments and control rooms are static and not subjected to these factors.
- Enclosed cabs on mobile equipment are generally designed with integrated heating, ventilation and air conditioning (HVAC) units with built-in filtration systems. Operator compartments and control rooms often do not have HVAC systems, which would require a different design.
- Control rooms can be much larger than operator cabs, which has an impact on intake pressurizer design considerations such as intake airflows. Also, workers have a greater tendency to congregate in these larger areas and enclosures since they are larger, resulting in a number of different factors that must be considered for an effective and safe design, with one particular issue being maintaining air quality, especially in regard to carbon dioxide (CO₂) levels.
- Operators in the enclosed cabs of mobile mining equipment tend to open and close the cab door and/ or enter and exit the cab much more frequently than operators in

compartments or control rooms, which affects how quickly the filtration system needs to handle new contaminants.

Methods

Baseline measurements

Before the filtration and pressurization unit was installed, measurements were taken to obtain the initial or baseline evaluation of the control room. As the respirable dust measurements could be affected by opening the door, particle counts were taken for 15 minutes during break times. This was done four times over the two days of testing. The pressure inside the room was measured to determine if there was positive pressure, which could hinder dust from being drawn into the room.

Particle counting measurements—Two ARTI/Met One HHPC-6 or two TSI OPS 3330 particle counters were used to record the inside- and outside-cab particle-size concentrations for one-minute periods over a 15-minute test. Once completed, the instruments were switched and the 15-minute test was repeated to eliminate the effects of instrument bias. This was repeated for a total of four tests.

The test medium was airborne particles present in the ambient air surrounding the control room. The last 10 minutes of data from each test were used to calculate the average outside and inside concentrations of the control room under steady-state conditions. The protection factors were determined from the cumulative submicrometer (0.3–1.0 micrometer) particle concentrations because most of the ambient-air particles resided in this size range. A protection factor for each test replicate was determined by dividing the average outside particle concentration by the average inside particle concentration at the operating test condition. The protection factor represents a reduction ratio of all the exterior and interior particles removed by the filtration system. Percent efficiency in reducing particles was determined by:

$$\% \text{ efficiency} = \frac{\text{outside concentration} - \text{inside concentration}}{\text{outside concentration}} \times 100 \quad (1)$$

To determine data precision, the 95 percent confidence limit was calculated by:

$$95\% \text{ confidence limit} = \pm t \times \frac{s}{\sqrt{N}} \quad (2)$$

where t is the t factor for the degrees of freedom, s is the standard deviation, and N is the number of samples.

Pressure measurements—All cab pressure measurements were taken with DP-CALC 5825 micromanometers (TSI Inc., Shoreview, MN). Measurements were taken every minute and recorded on the unit's internal data-logger. After each day of testing, the data were downloaded to a laptop computer and stored as an Excel file.

Installation of filtration and pressurization unit

The following design adjustments were made to the control room, shown in Fig. 1, to provide clean air and positive pressure:

- The control room was a block room measuring 3.05 m (10 ft) by 5.49 m (18 ft) by 2.44 m (8 ft), giving volume of about 41 m³ (1,440 cu ft), with a vestibule entrance. It had a window air conditioner and a wall heater. The window air conditioner was removed because it allowed exchange of inside and outside air, which could prevent achieving positive pressure. An AmericAire 9,000 Btu R410A 110 Volt Heat Pump Inverter Ductless Split System ductless air conditioner was installed instead.
- A Sy-Klone RESPA-CF Vortex Hyperflow unit was installed to provide filtered air and pressurization to the control room. Designed for enclosed cabs on mobile equipment, this unit is used by original equipment manufacturers as part of their cab systems and can also be installed onto existing enclosed cabs. It contains a powered cyclone preselector to eliminate large particles before the air is passed through a high-efficiency particulate arrestance (HEPA) or MERV-16 filter, to extend filter life. A fan pushes the air through the filter and into the control room, resulting in positive pressure.
- As the RESPA-CF unit was designed to operate off a 24-V power supply, a converter encased in a protective enclosure had to be connected to allow 120-V power to be used.
- Since previous studies had found a recirculation component (air from the room is passed through a filter and back into the room) to be crucial for enclosed cabs to limit exposure to re-entrained dust, a second Sy-Klone CFX unit was installed to recirculate and filter the air in the room.
- MERV-16 filters were used in these units because in the mining environment, they have been shown to be efficient in reducing respirable dust and to have a sufficient lifespan (Noll et al., 2014).
- A unidirectional design was used where the filtered air from the Sy-Klone units entered the room at the 1.52-m (5-ft) level but was directed upward toward the ceiling. The recirculation pickup point within the room was near the floor and was approximately 1 ft from the floor. This design was implemented to provide a unidirectional airflow pattern within the control room.

Post-analysis

A filtration and pressurization system is designed to provide clean air to a control room and produce positive pressure to prevent dust from entering the area. It is also important for the system to provide acceptable indoor air quality and not to cause a noise hazard. In this study, the following measurements were taken to determine the capability of the system installed in the control room:

- Efficiency of the system to reduce submicrometer particles.

- Positive pressure.
- Airflow.
- CO₂ concentrations.
- Noise levels.

The same particle-count and pressure measurements taken for baseline testing were repeated once the filtration and pressurization system was operational. In addition, to obtain visual evidence of positive pressure in the control room, smoke was produced using Sensidyne smoke tubes, the path of the smoke was recorded and photographs were taken when the system was on and off.

Airflow measurements were also collected since outside air was brought into the room mechanically. Airflow readings were measured for the intake and recirculation circuits of the control room's filtration system. A vane anemometer (Davis Instruments, Vernon Hills, IL) over the intake and recirculation filter inlet area was used to determine air velocity. The polyvinyl chloride piping for the intake and recirculation inlet areas had the same diameter as the anemometer, which allowed a precise fit. The airflow in cubic feet per minute (cfm) was calculated from the velocity and the outlet area. A Vaisala M70 monitor was used to measure CO₂ concentrations to ensure safe levels and to determine if there was acceptable air quality given that CO₂ is used as a surrogate for bioaerosols (ASHRAE, 2010; Fisk, 2000). A sample was collected every minute for one shift. The average concentration was calculated as well as the 95 percent confidence limit for the shift when the system was on. In addition, CO₂ concentration versus time was plotted.

Noise measurements were taken with a Spark 705 dosimeter to measure the effect of the filtration and pressurization system on noise levels. A sample was collected every 10 seconds for an entire shift. At the end of the shift, the system was shut down for an hour to record the noise when the two RESPA-CF units were turned off. The average equivalent continuous sound level, L_{eq} , and 95 percent confidence limit were calculated for when the system was on and off.

After one year, testing with the same filter was repeated for two days, so as to evaluate the system after dust had collected on the filter because a mechanical filter's efficiency increases with filter loading. A t-test using Sigma Plot 12.0 was performed comparing the efficiencies of the particle counters after initial installation and one year later to determine if there was statistical significance between values.

Results and discussion

Efficiency of system to reduce submicrometer particles

The filtration and pressurization system demonstrated significant reductions of over 87 percent in submicrometer particles. To determine the efficiency of the system and remove particles without the influence of opening and closing the door and of workers' stirring up particles inside the room, particle counts were taken inside and outside of the control room when the control room was not being used. Since dust was not generated, the test medium

was airborne particles less than 1 micrometer in size inside and outside of the room. As seen in Table 1, for baseline testing without the filtration and pressurization unit, more particles were inside the room than outside and the variability between tests was high, as evidenced by the high confidence limit of 29. Clearly, the air was not being cleaned before entering the room.

The filtration and pressurization system introduced clean air into the room while preventing dusty air from being drawn in, resulting in substantially fewer particles in the control room. When the unit was first installed, the average protection factor (PF) was 8, giving an 87 percent reduction in submicrometer particles, with much less variability between tests than the baseline testing. After one year, the PF increased to 25, giving a 94-percent reduction in submicrometer particles. The filters used in this system were mechanical, with efficiency increasing as they load with dust. In this case, the PF increased from 8 to 25, an efficiency increase from 87 percent to 94 percent, which was statistically significant, with a t-test ($p = 0.031$) demonstrating statistical significance between the two means.

Respirable dust particles are larger than the submicrometer particles used as the test medium in this study. Since filters are usually more efficient at larger particle sizes, the PF or efficiency of the filter to capture respirable dust should be equal to or greater than the PF or efficiency to capture submicrometer particles. Therefore, when the room is closed, the PF for respirable dust would be expected to be equal to or greater than 8 at first, corresponding to an 87 percent reduction in respirable dust or greater, and then to increase to 25 or greater, corresponding to a 94 percent or greater reduction in respirable dust, as the filter begins to load.

The PFs for this system were significant and similar to those observed in some enclosed cabs, with PF of 10 (Noll et al., 2012). An increase in intake airflow may improve the positive pressure inside the cab and result in improved PF. In addition, a two-filter intake system, where air passes through an intake filter and a final filter (both MERV-16) before entering the cab, has been shown to provide PFs as high as 1,000 (Organiscak et al., 2013). Designing the system after this model may provide better PFs than recorded in this study. It could also have an impact on airflow and pressure.

Ability of system to induce positive pressure

The system induced a positive pressure to prevent particles from entering the room. As seen in Fig. 2, there was no positive pressure before the system was installed and a slight positive pressure after installation, preventing dust from being drawn into the control room. The amount of pressure decreased after one year. The pressure is directly related to the intake airflow. Since the intake airflow went from 118 cfm to 80 cfm, this pressure decrease was expected. The pressure was between 0.01 and 0.02 inches of water gauge. Higher pressures would have been preferred, but the levels of pressure achieved have been shown to be sufficient in some enclosed cabs (Noll et al., 2014). This was visually observed with smoke tubes. As seen in Fig. 3, the smoke did not leave the room but was stagnant when no system was operating. Conversely, when the system was on, the smoke was drawn out of the room, meaning there was positive pressure.

Ability of system to achieve acceptable indoor air quality

The airflow into the room was 118 cfm when the filtration and pressurization system was initially installed. One to two workers usually occupied this room, so the airflow was higher than the ASHRAE-recommended ventilation rate of 20 cfm per person for acceptable indoor air quality for offices and laboratories (ASHRAE, 2010) as well as the minimum airflow standard for enclosed cabs of 25 cfm per person specified by the American Society of Agricultural and Biological Engineers (ASABE, 2003). The airflow also resulted in safe levels of CO₂, with average level of 773±16 ppm and maximum level of 1,510 ppm. Even the maximum concentration was well below the Occupational Safety and Health Administration's time-weighted average (TWA) permissible exposure limit of 5,000 ppm and short-term exposure limit (STEL) of 30,000 ppm. Carbon dioxide concentrations were also used to identify and manage adequate ventilation because they can indicate buildup of other contaminants such as bioaerosols, which can result in human discomfort (ASHRAE, 2010; Fisk, 2000). For CO₂, ASHRAE considers 1,000 ppm when outside air is 300 ppm (or 1,100 ppm with 400 ppm outside air) and below as a guideline to indicate adequate ventilation and acceptable indoor air quality (ASHRAE, 2010). As seen in Fig. 4, adequate ventilation was provided to the control room, with the CO₂ concentration usually below 1,100 ppm.

After one year, the airflow decreased to 80 cfm, which was still higher than the ASHRAE-recommended ventilation, and CO₂ levels were still safe, with the average at 754±10 ppm and the maximum at 1,470 ppm. As seen in Fig. 4, except for a few short peaks, the CO₂ concentrations met the ASHRAE recommendation for acceptable air quality. Eventually, the airflow will decrease to unacceptable levels, indicating the need for a filter change.

Effect of system on noise levels

Because of the fans in both RESPA-CF units in the control room, one for intake air and one for recirculation, as part of the filtration and pressurization system, noise levels were measured. As expected, there was an increase in noise with the system. When the system was off, sound levels were 63±0.1 dBA, which increased to 74±0.4 dBA when the system was initially installed. After one year of filter loading, the noise was measured at 72±0.2 dBA, indicating very little change. While these noise levels are not considered harmful and are similar to the noise experienced in some cabs of mobile equipment, some workers found the increase in noise levels to be noticeable. Therefore, a next step for this system would be to develop methods to reduce noise.

Conclusions

In this study at a mineral processing plant, the installation in a control room of a filtration and pressurization unit similar to those used in enclosed cabs was successful. Reductions in submicrometer particles of over 87 percent were observed. Positive pressure to help prevent dust from being drawn into the control room was produced, and the airflow was high enough to produce safe levels of CO₂ and acceptable air quality. With a mechanical filter, filter efficiency and the pressure drop across the filter increases as the filter begins to load. The increase in pressure drop will decrease airflow, which will eventually result in unacceptable

air quality, and potentially cause leaks, leading to a decrease in the efficiency of the system to reduce respirable dust. In this case, after one year, particle reduction rose to 94 percent, from the initial 87 percent, and airflow decreased to 80 cfm, from 118 cfm. After a year, the reduction efficiency was higher and the airflow still provided acceptable indoor air quality, though eventually it will not provide the desired ventilation and the filter will need to be changed.

A negative impact of this filtration and pressurization system was an increase in noise to 74 dBA from 63 dBA. The higher noise level was not dangerous to health but was a source of frustration or viewed as a nuisance by some workers. Therefore, efforts are currently underway to investigate methods for reducing the noise in these applications.

From this study, the factors to consider when designing a filtration and pressurization unit for a control room or operator booth are:

- Power requirements: A converter had to be used as the filtration and pressurization unit was designed for 24-V DC power but there was only 120-V AC power. Pressurization and filtration units operating on 120-V AC power may be available soon.
- HVAC: The most important requirement of an HVAC system used with a filtration and pressurization unit is that it does not allow exchange of air inside and outside of the control room or booth. In this case, an electric wall heater and ductless air conditioner were used. One could also integrate the HVAC system with the filtration and pressurization unit.
- Integrity of room or booth: How well the room is sealed should be determined before installing a filtration and pressurization unit. The control room in this study was a block building and well sealed.
- Size of room: Two units worked well for the size of the study room to provide enough intake and recirculation air. However, more positive pressure may be beneficial and this could be provided with more intake air. For larger rooms, more intake air may be needed.
- Type of filter: A MERV-16 filter worked well in this case. A HEPA filter should also reduce dust well but may be more restrictive to airflow.
- System indicator: A system indicator device would be beneficial to notify the worker when there is a problem with the system or when the filter needs to be changed. NIOSH is currently studying the use of pressure monitors to accomplish this task.
- Noise: Some noise dampening should be considered when designing the system for a control room or operator booth.
- Unidirectional design: The intake air was brought into the room at the top and the recirculation air was drawn from the bottom to gain the benefits of a unidirectional design.

- Protection factor of system: The PFs for this system were significant and are similar to those observed in some enclosed cabs.

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Figure 1.

(a)–(b) Filtration and pressurization units on the outside of the control room. (c) Control-room interior: The polyvinyl chloride pipe coming in on the top left is the intake (filtered air) to the recirculation while that on the top right is the filtered outside air or intake, and the tubing near the floor is the intake for the recirculation.

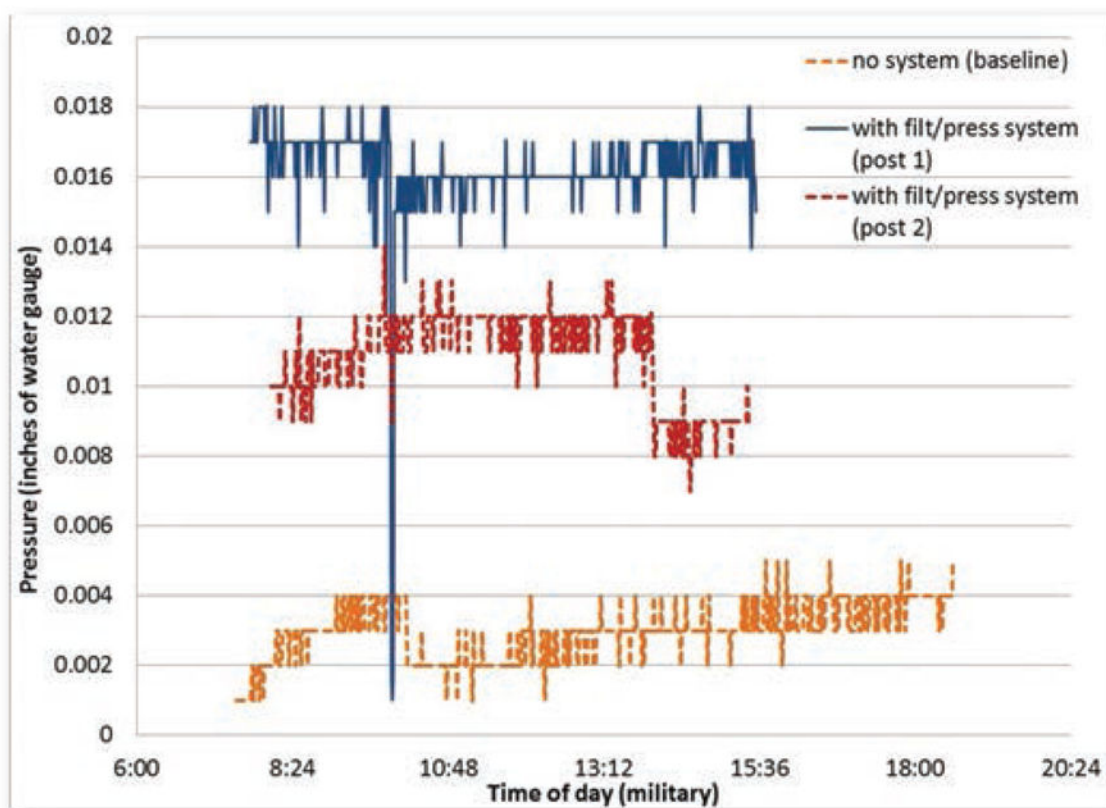


Figure 2.
Pressure inside the control room over a shift with and without the filtration and pressurization unit.



Figure 3.

(a) System off: Smoke from a smoke tube was lingering inside the room because there was no positive pressure. (b) System on: Smoke was leaving the room as positive pressure was causing contaminants to be pushed out of the room.

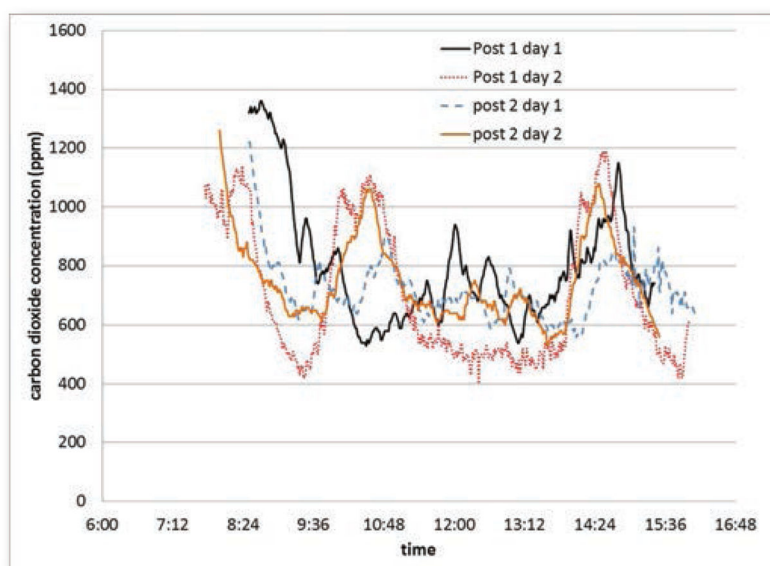


Figure 4. Variation of CO₂ concentration inside the control room while the filtration and pressurization unit was operating.

Table 1

Protection factor and efficiency of the control room via particle counting.

Sample	Description	Protection factor	Efficiency (%)
Baseline	No filtration and pressurization unit.	0.79±0.17	36±29
Post 1	First two days of operating the filtration and pressurization unit.	8±3	87±4
Post 2	One year after installation of filtration and pressurization unit.	25±15	94±4